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Thermal economic analysis on LiBr refrigeration -heat pump system applied in CCHP system

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Abstract

LiBr refrigeration cooling water contains a lot of low-temperature heat source, can use this part of the heat source heat boiler feed water. This paper introduced LiBr refrigeration – heat pump system which recovery heat of the LiBr refrigeration cooling water by heat pump system to heat the feed water of boiler. Hot economic analysis on the system has been performed based on the experimental data. Results show that LiBr refrigeration-heat pump system brings 26.6 percent decrease in primary energy rate consumption comparing with the combined heat and power production system(CHP) and separate generation of cold;

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Keywords: hot economic analysis; heat pump system; heat recovery; exhaust heat; CCHP system;

1. Introuction

Combined cooling, heating and power (CCHP) is the production of power (electrical or mechanical) and usable heat from a single fuel source. A mass of lower quality exhaust heat produced in the process of the generation of cold. This part of exhaust heat typically is taken away by cooling water and lost to the atmosphere through cooling tower ^[1]. A new heat recovery technique for LiBr refrigeration-heat pump system applied in CCHP system is proposed. The system can recover heat of the LiBr refrigeration cooling water to heat the demineralized water of boiler.

CCHP systems possess some unique advantages, such as improved overall fuel energy utilization ratio, reduced CO₂ emission, and increased reliability of the energy supply network ^[2].However, it is difficult to reflect the energy saving potential of various practical CCHP systems when the differences of

various practical efficiencies are ignored. In practice, efficiencies of CCHP units strongly depend on the scale and types of various units. Consequently, it is difficult to illustrate energy utilization performances of various CCHP systems in some simply uniform styles. Marantans^[3] has analyzed the realistic energy savings based on the practical efficiencies of CHP systems and illustrated the importance of reference situations selection. Jalalzadeh-Azar^[4] performed an analysis of energy cost and primary energy consumption of CCHP systems operating under FEL and FTL strategies while utilizing a gas fired microturbine in different climates. The results yielded an 11% reduction in total energy consumption when the CCHP operates according to FTL versus that of FEL. But the appropriate reference situation is not suggested and discussed the effect-factor of energy saving of the CCHP system with recovery exhaust heat of LiBr refrigeration system. The present study investigates a small scale CCHP system with *LiBr* refrigeration -heat pump system.

2. Thermal system

The CCHP system with using the cooling water of LiBr refrigeration system to heat boiler feed water was shown in Fig1. Coal was sent into fluidized bed boiler to burn out and generate heat to heat demineralized water into steam. Steam was sent into steam turbine acting to generate electricity. Part of the back-pressure steam was sent into heat consuming installation to supply heat, part of the back-pressure steam was sent into LiBr refrigeration to generate refrigerating effect, 7°C Chilled water was sent to cold users. In the refrigeration process 38°C cooling water was produced. The 38°C cooling water is acted as the heat source to heat the 26°C treated water, heat the demineralized water to 65°C through the heat pump. The heated demineralized water was sent into the steam deaerator water combined with the back-pressure turbine steam from turbine to evacuate oxygen. The deoxygenation water was sent into the boiler to be heated. This is the thermal cycle process of the system.

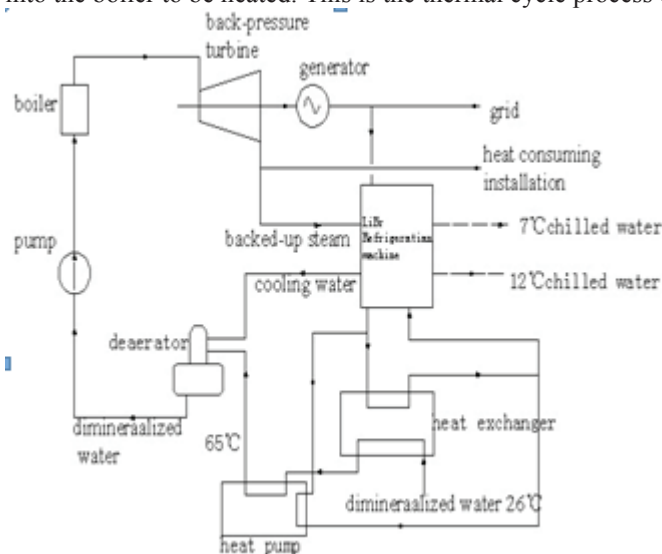


Fig 1. Schematic diagram of the CCHP system with utilization of LiBr refrigeration-heat pump system

3. Test data and test results

The tests studied the operating characteristics of the LiBr refrigeration-heat pump system has been done. The texts results are shown in Table 1, Table 2. Produced 424.24kW cold, need to consume

347.47kW steam heat, heat pump system produce 854.6kW heat to heat the demineralized water of boiler, power consumption of the compressor heat pump system is 139.5kW. Average COP_R of the LiBr refrigeration system is 1.22. Average COP_P of the heat pump system is 6.126. For LiBr refrigeration-heat pump system, the evaporator refrigerant heat of the heat pump system should be equal to the heat emitted from lithium bromide absorption refrigeration system. From Table 1, Table 2 shows, the evaporator refrigerant heat of the heat pump system is slightly less than the heat emitted from lithium bromide absorption refrigeration system, which is due to the loss of the cooling water pipe from lithium bromide chiller system to the heat pump system.

Table1. LiBr refrigeration system operating characteristics

		Average
Chilled water	Inlet T (°C)	12.2
	Output T (°C)	7.2
	Flow(t/h)	72.911
Cooling water	Inlet T (°C)	33.8
	Output T (°C)	39
	Flow(t/h)	127.2
Steam After valve	Pressure(MPa)	0.509
	T (°C)	164.8
	Flow(t/h)	0.518
	Condensate T (°C)	85.1
Cooling water quantity(kW/h)		777.51
Steam heat quantity(kW/h)		347.45
Refrigerating capacity(kW/h)		424.92
COP_R		1.22

Table2. Heat pump system operating characteristics

		Average
Demineralized water	Inlet T (°C)	32.7
	Output T (°C)	67.8
	Flow(t/h)	20.9
Cooling water	Inlet T (°C)	39.1
	Output T (°C)	34.1
	Flow(t/h)	127.2
Condensation heat transfer (kW/h)		854.60
Evaporative heat transfer(kW/h)		749.57
Compressor power (kW/h)		139.5
COP_P		6.126

4. IV. Evaluation and calcution of designed cchp energy efficiency

The well known evaluation of the energy efficiency of systems for refrigeration system and heat pump system by means of the value of coefficient of performance (COP) is not a satisfactory criterion for the proposed trigeneration systems compared with the conventional CHP system and separate generation of cold ^[5]. The decisive value for the energy efficiency evaluation of such energy

cycles is the primary energy rate (PER). The PER is the ratio of primary energy demand to the required output, and consequently, the system with the lowest value of PER is considered the best with regard to energy consumption [6-7]. The PER values for the designed CCHP and independent production of the individual energy flows can be expressed on the basis of the given PER definition.

The PER value for the CCHP can be expressed by the following equation:

$$\text{PER}_{\text{CCHP}} = \frac{Q_{\text{pc}}}{\sum Q_{\text{h}} + \sum Q_{\text{c}} + \sum P_{\text{c}}} \quad (1)$$

Q_{PC} represents the primary energy demand of the CCHP system. On the basis of the heating efficiency of a boiler η_{b} , the generating efficiency of a thermal power station η_{e} , Q_{PC} can be expressed by the following equation:

$$Q_{\text{PC}} = \frac{\sum Q_{\text{HCCHP}}}{\eta_{\text{b}}} + \frac{\sum P_{\text{CCCHP}}}{\eta_{\text{e}}} \quad (2)$$

The PER value for the independent system can be expressed by the following equation:

$$\text{PER}_{\text{s}} = \frac{Q_{\text{PS}}}{\sum Q_{\text{h}} + \sum Q_{\text{c}} + \sum P_{\text{c}}} \quad (3)$$

Q_{PS} represents the primary energy demand of the CHP system and separate generation of cold. Q_{PS} can be expressed by the following equation:

$$Q_{\text{PS}} = \frac{\sum Q_{\text{HS}}}{\eta_{\text{b}}} + \frac{\sum P_{\text{CS}}}{\eta_{\text{e}}} \quad (4)$$

The comparative saving of primary energy demand Δq is defined as the ratio of the saved primary energy in the designed CCHP system to the CHP system and separate generation of cold:

$$\Delta q = \frac{Q_{\text{PS}} - Q_{\text{PC}}}{Q_{\text{PS}}} \quad (5)$$

Fig2. shows energy consumption and production of CCHP system. Fig3. shows energy consumption and production of CHP system and separate generation of cold. In CCHP system heat products in heat pump system through recovery exhaust heat of LiBr refrigeration system. In CHP system and separate generation of cold heat is obtained by absorption heat of steam.

Table3. is the values of PER CCHP system and CHP system and separate generation of cold. CCHP system consumes 0.518t/h steam pressure 0.509Mpa, This is counted as CHP system and separate generation of cold to 0.446t / h. 0.446t/h main steam generate 32.72kW electric power. In the CHP system and separate generation of cold, production 854.6kW heat needs 1.093t/h CHP system and separate generation of cold. 1.093 t/h main steam generate 78.44kW electric power. In order to obtain same amount of electricity, CCHP system needs compensate 45.72kW electric power.

It can be seen that the PER_{CCHP} of the CCHP system is 0.761, the PER_{s} of CHP system and separate generation of cold is 1.307. CCHP system brings 26.6 percent decrease in primary energy rate consumption comparing with the combined heat and power production system (CHP) and separate generation of cold.

Table3. Values of PER of CCHP system and CHP system and separate generation of cold

System	Consumption and production	Energy sources	Value	primary energy
CCHP system	consumption	Steam(kW)	390.21	433.69
		Electric power of the compressor heat pump system(kW)	139.5	398.6
		Electric power of the cooling water pump and the chilled water(kW)	24.71	70.6
		Compensation electric power	45.72	130.63

		Toal primary energy (kW)		1033.5
	production	Cold(kW)	424.92	
		Heat(kW)	854.6	
		Electric power(kW)	78.44	
		Total	1357.96	
	PER _{CCHP}	0.761		
CHP system and separate generation of cold	consumption	Steam(kW)	935.82	1039.8
		Electric power of electric refrigeration (kW)	129.06	368.74
		Toal primary energy (kW)		1408.54
	production	Cold(kW)	424.92	
		Heat(kW)	854.6	
		Electric power(kW)	78.44	
		Total	1357.96	
	PER _s	1.037		
Δq	26.60%			

5. Conclusion

Combined cooling, heating and power(CCHP) system can increase energy conversion efficiency, improve overall fuel energy utilization ratio. CCHP is a broad term referring to a set of integrated technologies such as turbines, reciprocating engines, microturbines, fuel cells, heat pumps, thermally activated technologies, and/or waste heat recovery technologies that can be implemented in different configurations to suit different needs. LiBr refrigeration-heat pump system recovers heat of the LiBr refrigeration cooling water to heat the demineralized water of boiler to increase energy conversion efficiency. CCHP system brings 26.6 percent decrease in primary energy rate consumption comparing with the combined heat and power production system(CHP) and separate generation of cold.

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